ADA

ANALYSIS OF DEBRIS FROM HELICOPTERS FROM THE FIELD

INTERIM REPORT
TFLRF No. 402

by

Gary B. Bessee

U.S. Army TARDEC Fuels and Lubricants Research Facility
Southwest Research Institute® (SwRI®)
San Antonio, TX

for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Contract No. DAAE-07-99-C-L053 (WD49)

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14. ABSTRACT

This program investigated helicopter operational field issues encountered by the U.S. Army Aviation Engineering Directorate. All of these field issues involved contaminated fuel problems that created operational/flight safety issues. Two of the incidents involved plugged fuel filters that were directly related to super absorbent polymer (SAP) migration from water absorbent monitors. The third incident also involved a plugged fuel filter, but this debris was from an unknown, external source.

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EXECUTIVE SUMMARY

This program investigated helicopter operational field issues encountered by the U.S. Army Aviation Engineering Directorate. All of these field issues involved contaminated fuel problems that created operational/flight safety issues. Two of the incidents involved plugged fuel filters that were directly related to super absorbent polymer (SAP) migration from water absorbent monitors. The third incident also involved a plugged fuel filter, but this debris was from an unknown, external source.

FOREWORD/ACKNOWLEDGMENTS

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ACRONYMS AND ABBREVIATIONS

psi	pounds per square inch
rpm	rotation(s) per minute
SAE	Society of Automotive Engineers
SwRI®	Southwest Research Institute®
TACOM	Tank and Automotive Command
TAN	Total Acid Number
TARDEC	Tank-Automotive RD&E Center
TBN	Total Base Number
TFLRF	TARDEC Fuel and Lubricants Research Facility
TGA	Thermo Gravimetric Analysis
TWV	Tactical Wheeled Vehicle
WD	Work Directive

1.0 BACKGROUND AND OBJECTIVES

The U.S. Army Aviation Engineering Directorate has experienced several contaminated fuel issues that have resulted in crashes or operational issues. The objective of Work Directive 49 was to analyze fuel, fuel and filter debris, aircraft fuel system components, and fuel delivery systems to determine sources and causes of these issues.

2.0 FIELD ISSUE #1

A helicopter crash was investigated to resolve the cause of failure. The analysis in this effort concentrated on identification of the debris and analysis of fuel filtration and elements.

The analysis for Field Issue #1 consisted of:

- Perform engineering analysis to determine the composition of debris found in U.S. Army helicopter Serial Number 92-00403 and on the fuel filters installed on the helicopter. The U.S. Army Aviation Engineering Directorate provided the filters and the debris to be analyzed.

- Analysis was performed on the fuel supply system, the internal main fuel cell, and on the fuel truck delivery filtration systems and elements—specifically, the fuel truck water absorbent monitors.

2.1 Background

The aviation industry as a whole has had issues with media migration with water absorbent monitors. For reasons not fully understood, the super absorbent polymer (SAP) migrates downstream of the filter and has been shown to cause problems. In 2006, several U.S. Air Force aircrafts had flame-outs during flight at Sheppard Air Force Base. The investigation by the U.S. Air Force found SAP in the fuel controls, which was attributed to causing the problem. Single

element tests (SET) were performed at Southwest Research Institute® (SwRI®) to determine if any media migration was occurring with the water absorbing monitors installed at Sheppard Air Force Base. Four 6-inch diameter monitors were evaluated per a modified API/IP 1583 protocol. The evaluations were conducted using the 50-ppm water challenge. All monitors captured the water, but media migration was shown using particle counting, turbidity analysis, and SEM analysis of debris captured downstream of the test monitors.

Both the government and the commercial aviation industry have performed research to determine the extent of SAP migration, possible causes, and potential effects.

2.2 Scope of Work

The scope of work for Field Issue #1 was to identify the debris captured on various fuel filters from aircraft MH-47E, A/C 92-00403.

2.3 Methodology

The fuel filters were back-flushed with iso-octane to remove the debris and then filtered through 0.8-μm membranes to capture the debris. The following analyses were performed on the debris:

- Copper Sulfate test
- Elemental analysis by EDS
- FTIR
- Optical analysis

The copper sulfate test is used by the diaper industry to determine the distribution of SAP in the diapers. An ion exchange process occurs between the copper in the copper sulfate and the metal in the SAP. This ion exchange process will turn the SAP blue in color.

2.4 Results

Photos of the filters are shown in Figures 1 and 2.

Figure 1. #1 Engine

Figure 2. #2 Engine Filter, as Received

The preliminary results of the fuel filter analysis are as follows:

- Optical photos of filter debris – Copper Sulfate Test (Figures 3–8)
- FTIR spectra of filter debris (Figures 9–13)
- Optical photos (Figures 14–17)
- Optical photo – New water absorbent monitor (Figure 18)
- Elemental Analysis (Table 1)
- Optical photos of sealing fuel bladder material (Figures 19–21)
- Optical pictures of plugged #1 Main Fuel Filter and "smudge" from fuel tank (Figures 22–23)

The copper sulfate analysis did not yield the expected results. However, the elemental analysis revealed copper and aluminum already in the fuel, which would complete the ion exchange process and not allow the laboratory reaction to occur. By all other accounts, the evidence collected to date suggests that a fuel monitor ruptured somewhere upstream in the system. The FTIR spectra of the fine debris shown in Figure 8 (#1 Engine) and Figure 10 (#2 Engine) show characteristics that we typically associate with the presence of SAP. This evidence can be further corroborated by the levels of sodium seen in the elemental analysis (Table 1). The optical photos shown in Figures 16–17 are also confirming evidence, as they show various layers of material that we believe belong to a specific manufacturer of fuel monitors. These layers can be compared with the cut-away of the water absorbent monitor shown in Figure 18.

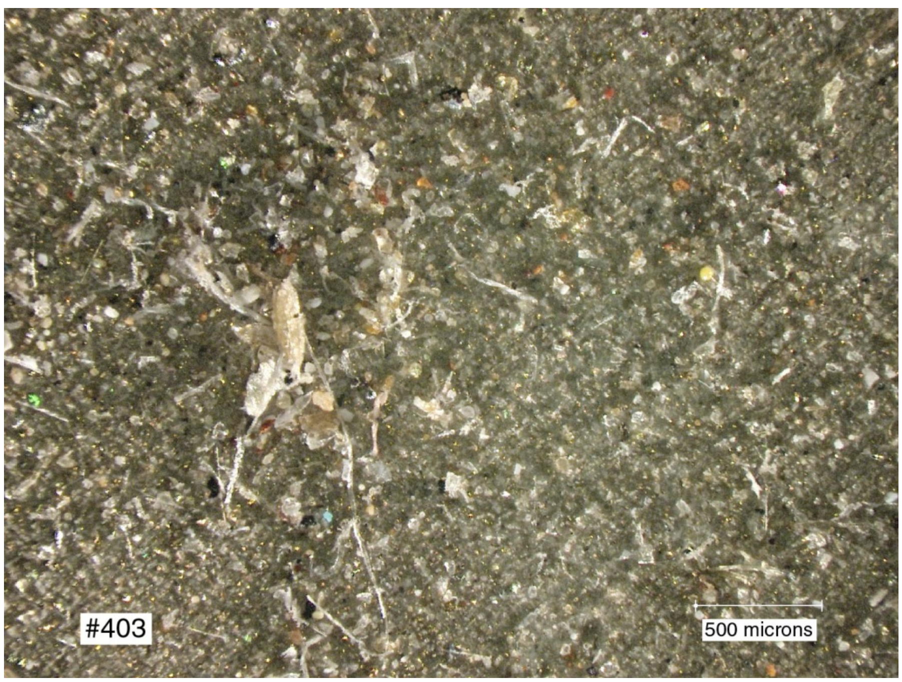

Figure 3. SEM Photos - #403 (500 µm)

Figure 4. SEM Photos - #403 (200 µm)

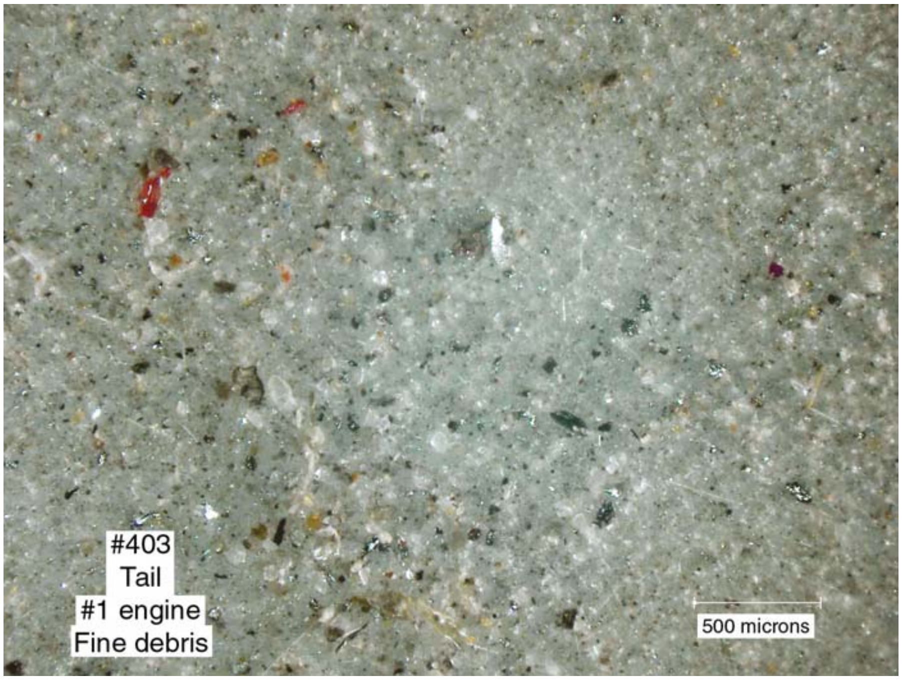

Figure 5. SEM Photos – #1 Engine Fine Debris (500 µm)

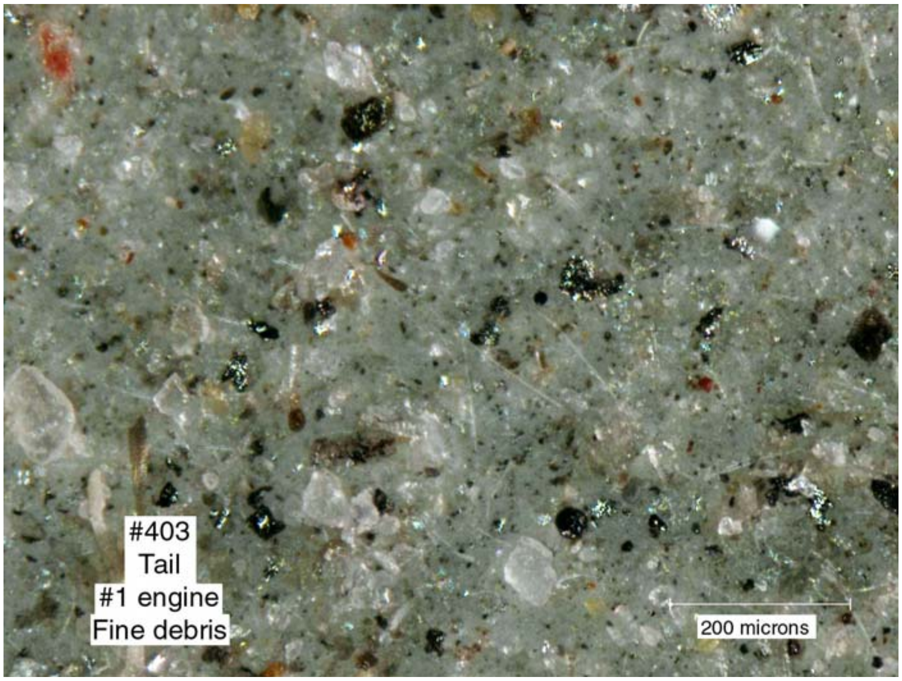

Figure 6. SEM Photos – #1 Engine Fine Debris (200 μm)

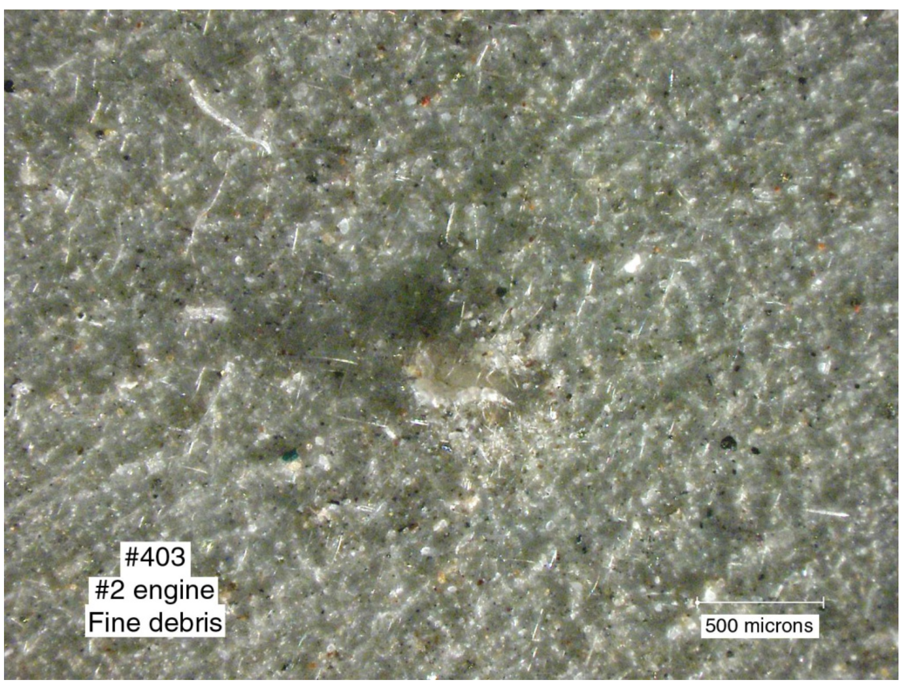

Figure 7. SEM Photos – #2 Engine Fine Debris (500 μm)

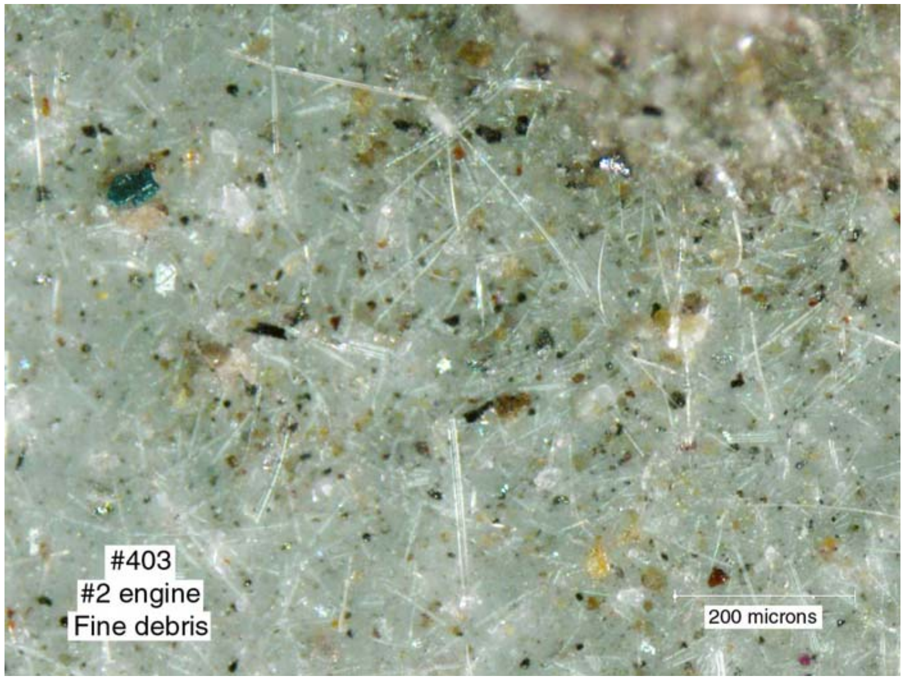

Figure 8. SEM Photos – #2 Engine Fine Debris (200 µm)

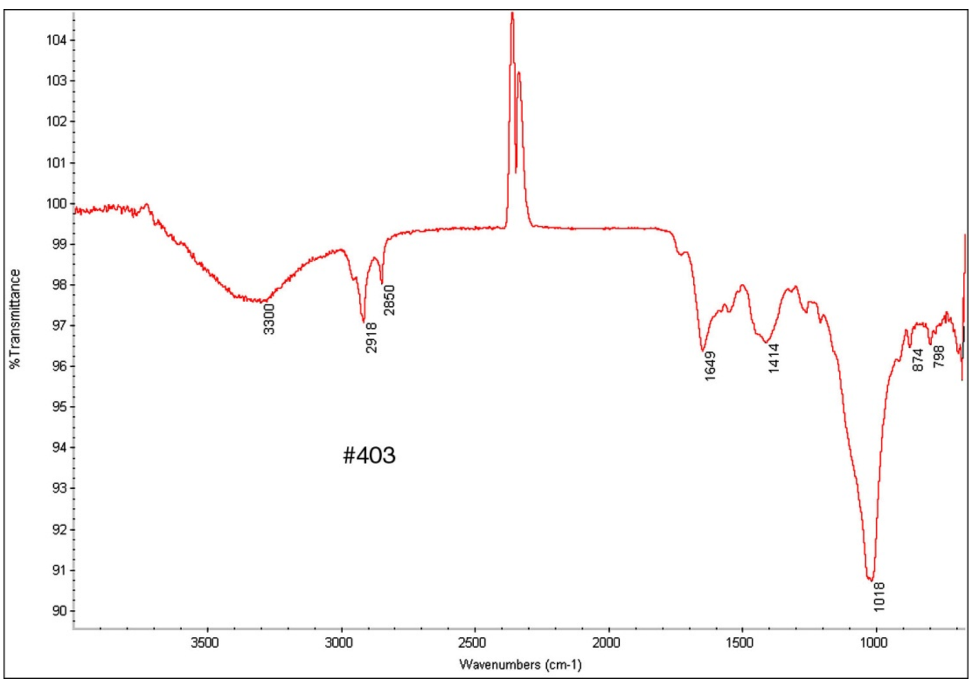

Figure 9. FTIR Spectrum – #403

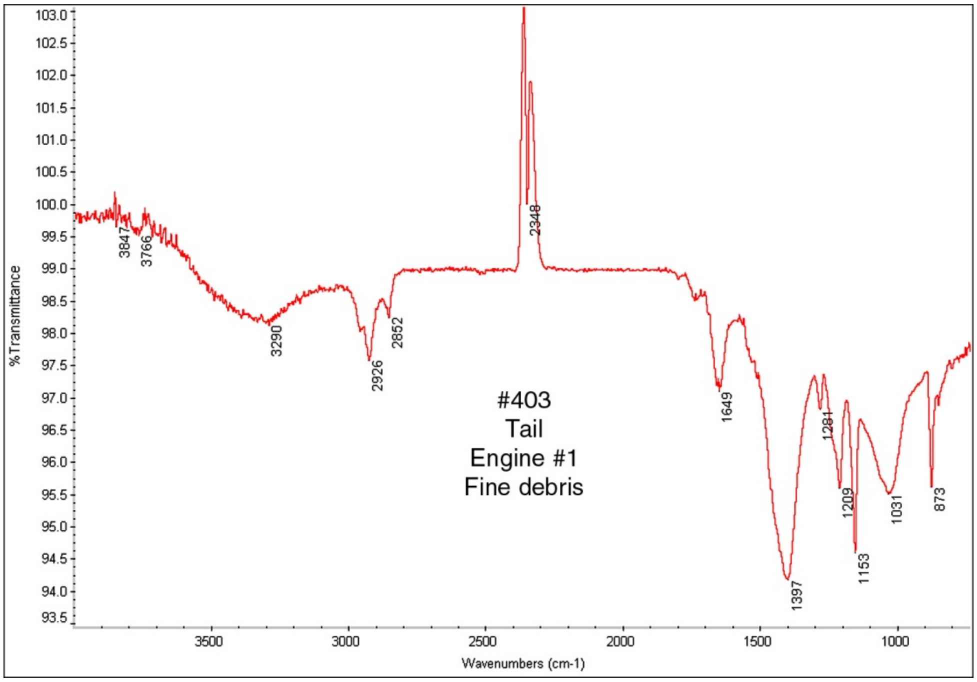

Figure 10. FTIR Spectrum – #1 Engine Fine Debris

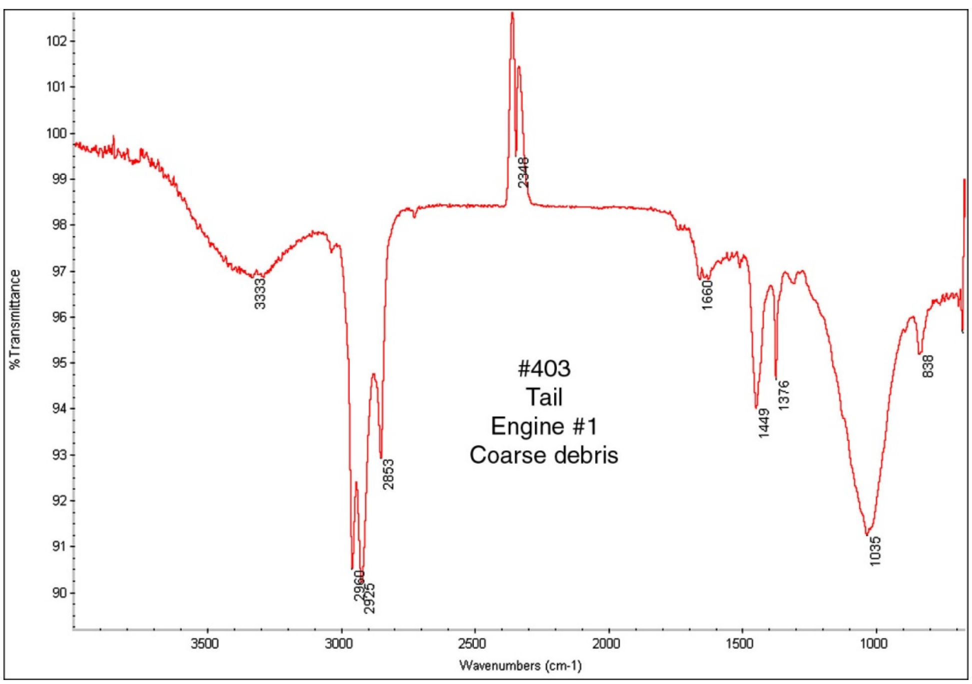

Figure 11. FTIR Spectrum – #1 Engine Coarse Debris

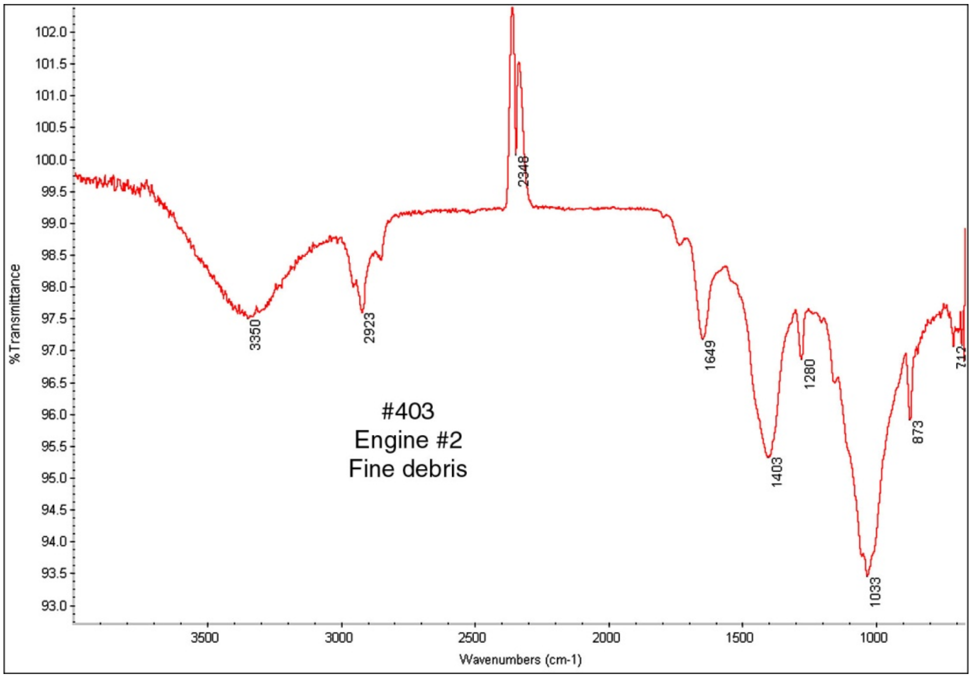

Figure 12. FTIR Spectrum – #2 Engine Fine Debris

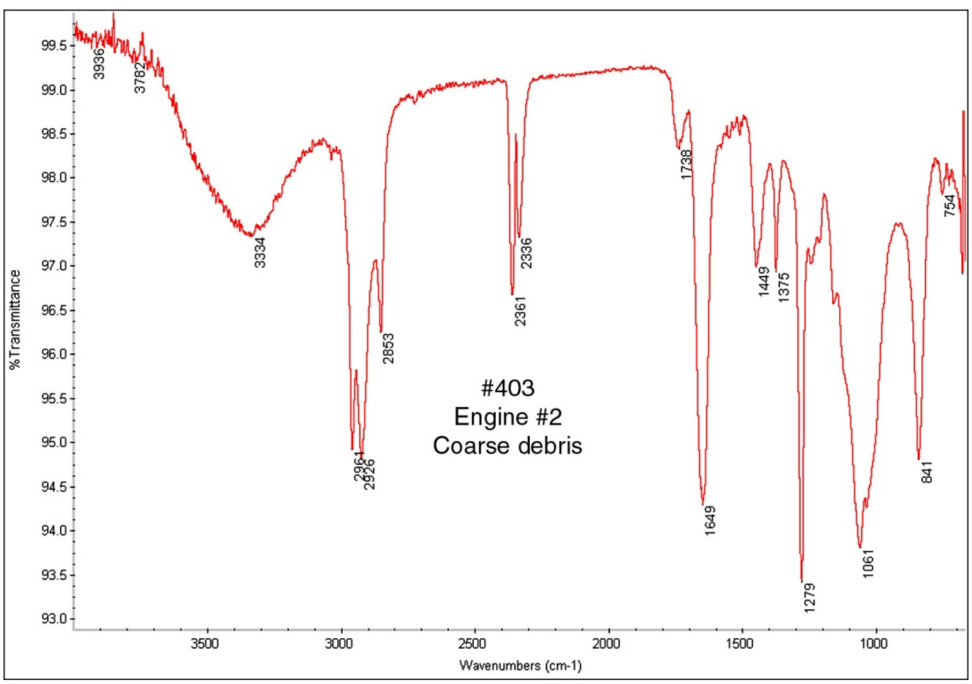

Figure 13. FTIR Spectrum – #2 Engine Coarse Debris

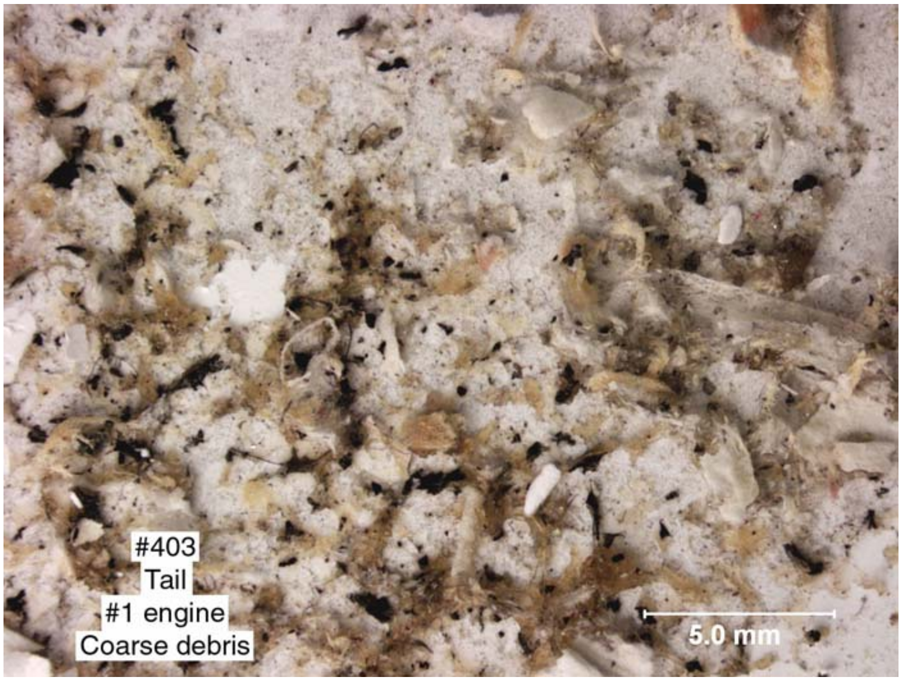

Figure 14. Optical Photo – #1 Engine Coarse Debris (5.0 mm)

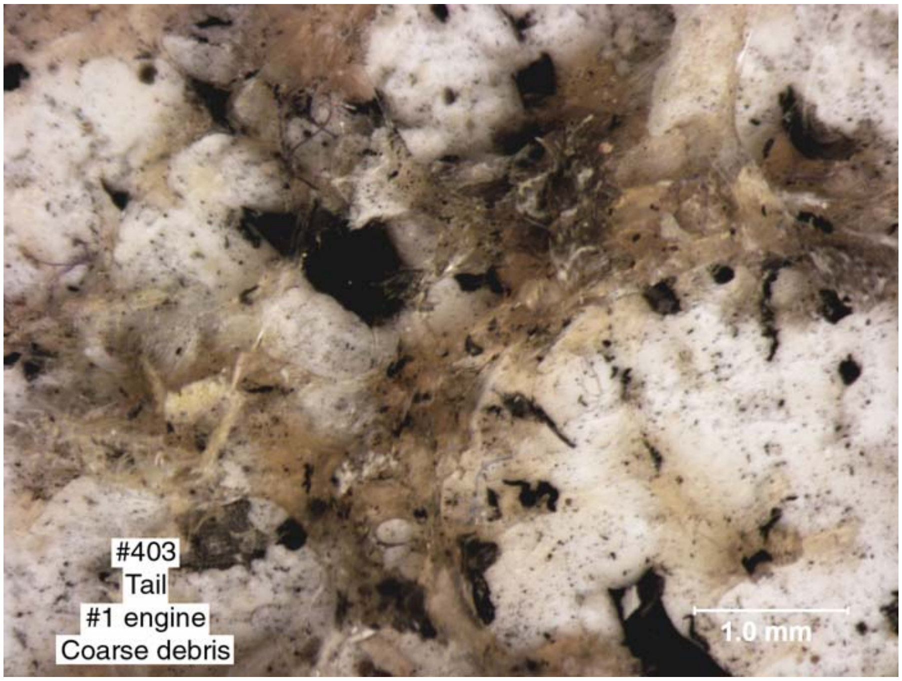

Figure 15. Optical Photo – #1 Engine Coarse Debris (1.0 mm)

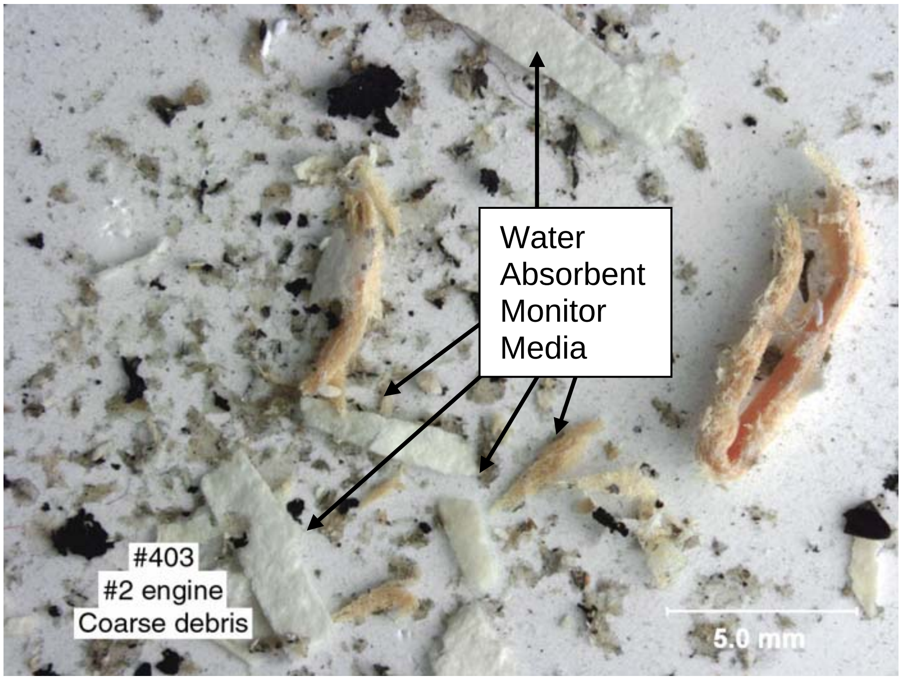

Figure 16. Optical Photo – #2 Engine Coarse Debris (5.0 mm)

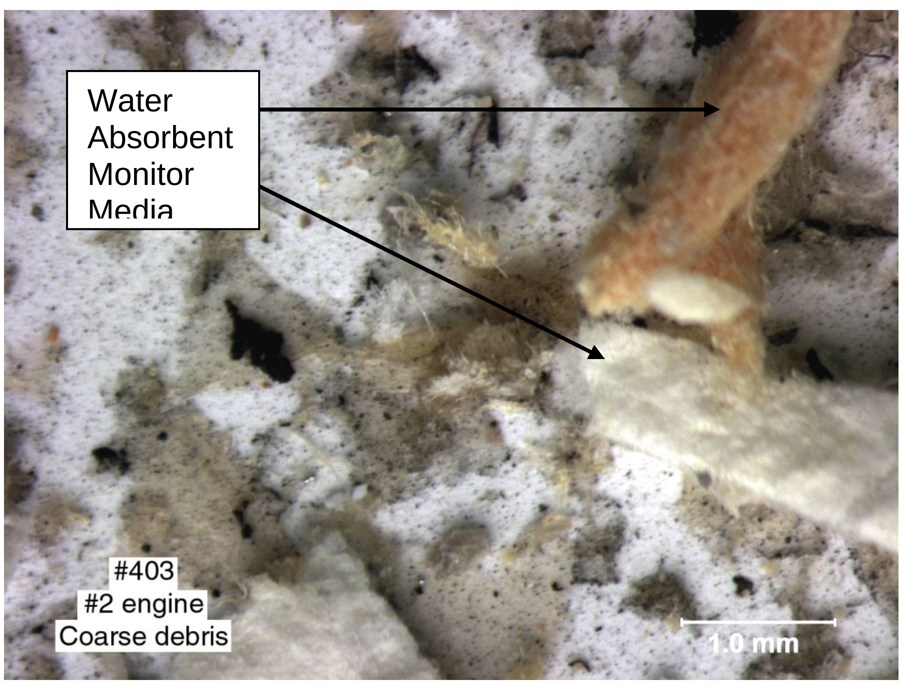

Figure 17. Optical Photo – #2 Engine Coarse Debris (1.0 mm)

Figure 18. Cut Away of New Water Absorbent Monitor

Table 1. Elemental Analysis

Element	#403	#1 Engine Coarse Debris	#1 Engine Fine Debris	#2 Engine Coarse Debris	#2 Engine Fine Debris
	wt%	wt%	wt%	wt%	wt%
Na	11.31	11.68	4.57	14.84	11.09
Mg	3.65	20.48	2.65	5.31	2.55
Al	15.66	4.79	11.11	9.69	7.09
Si	27.37	32.58	17.16	44.92	36.28
P	0.6	2.70	0.56	—	—
S	3.41	13.03	2.17	3.85	1.45
Cl	7.08	2.96	2.83	3.02	2.21
K	3.18	2.48	1.43	3.15	2.34
Ca	6.51	2.50	47.65	2.97	25.59
Ti	2.11	—	3.63	0.85	1.21
Cr	0.45	—	0.58	—	—
Mn	0.26	—	—	—	—
Fe	3.64	—	5.03	—	3.16
Ni	0.53	—	—	—	0.10
Cu	10.63	—	—	—	—
Zn	3.6	3.09	—	7.06	2.47
Ba	—	3.72	0.63	4.35	4.45

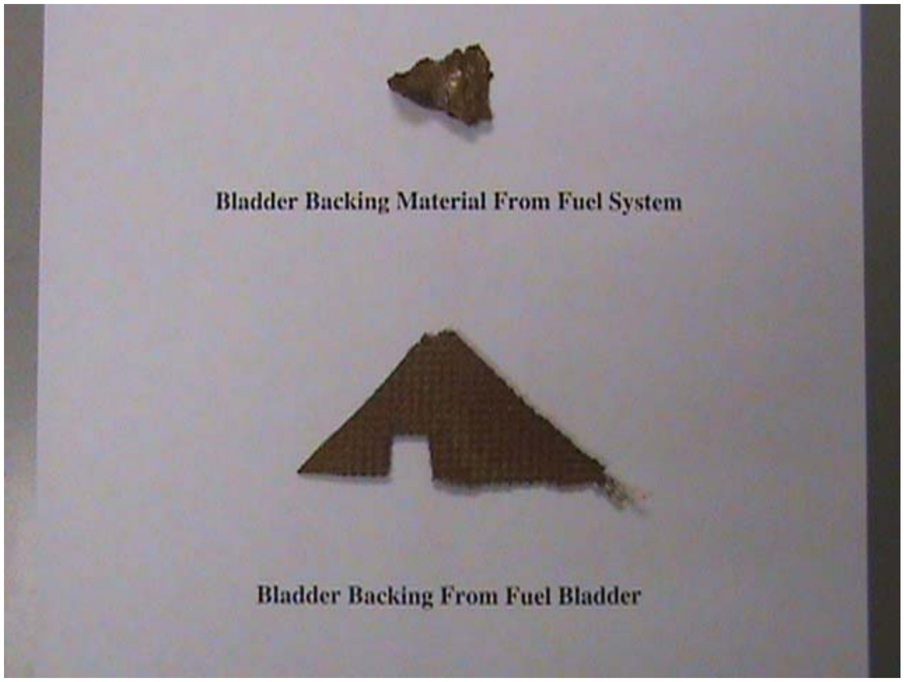

Figure 19. Self-Sealing Fuel Bladder and Bladder Sealant

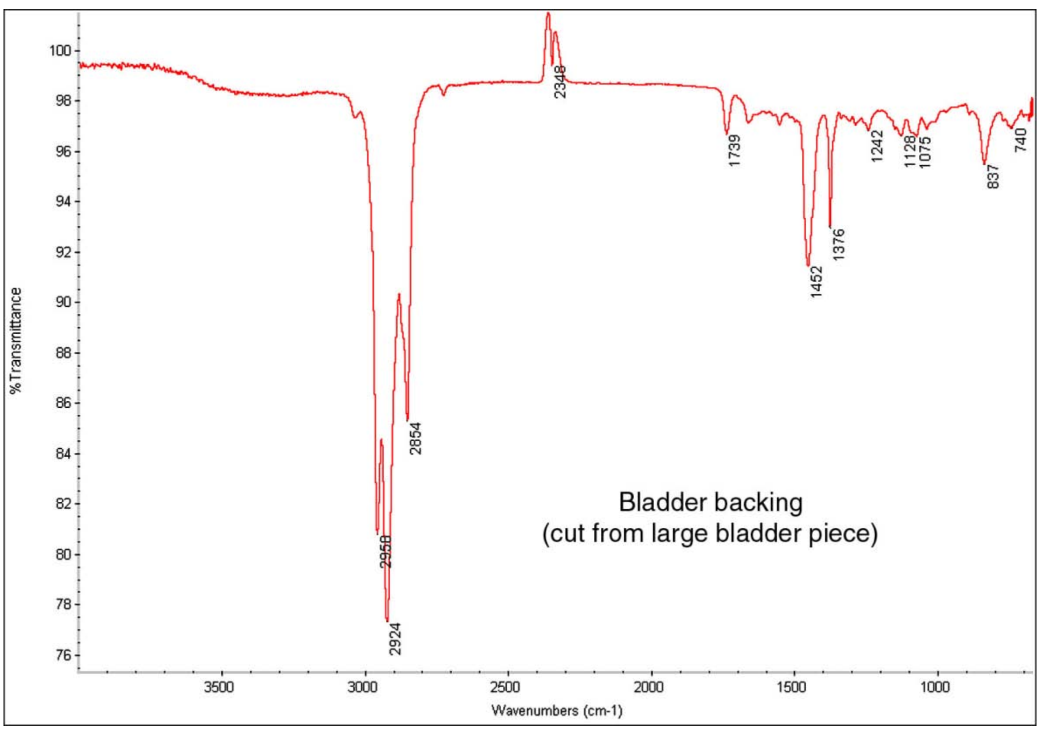

Figure 20. FTIR of Self-Sealing Material from Bladder

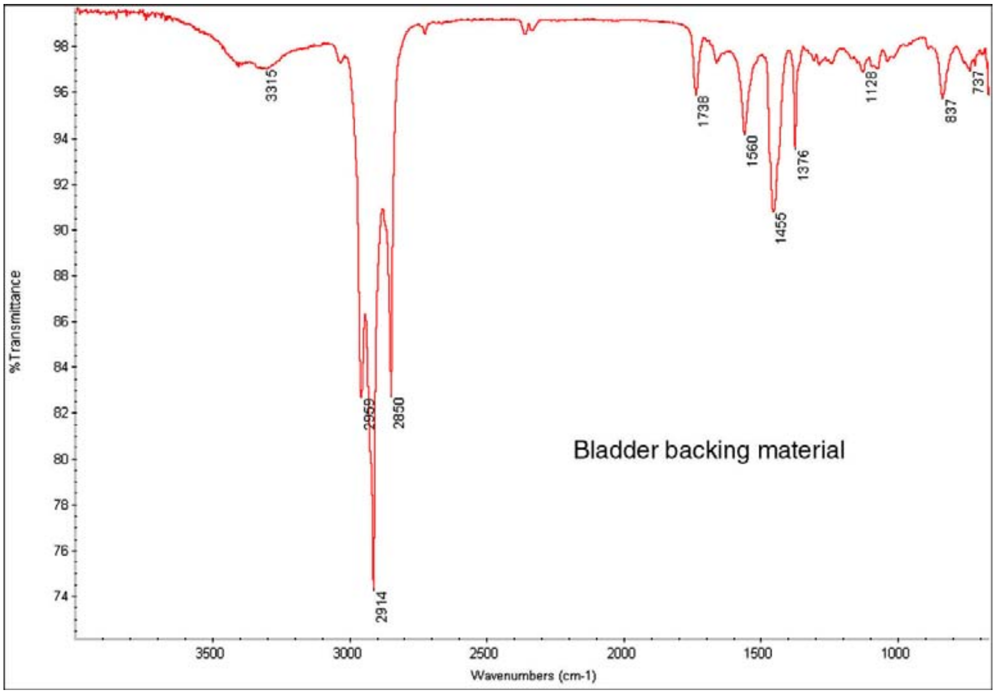

Figure 21. FTIR of Bladder Sealing Material from Fuel Tank

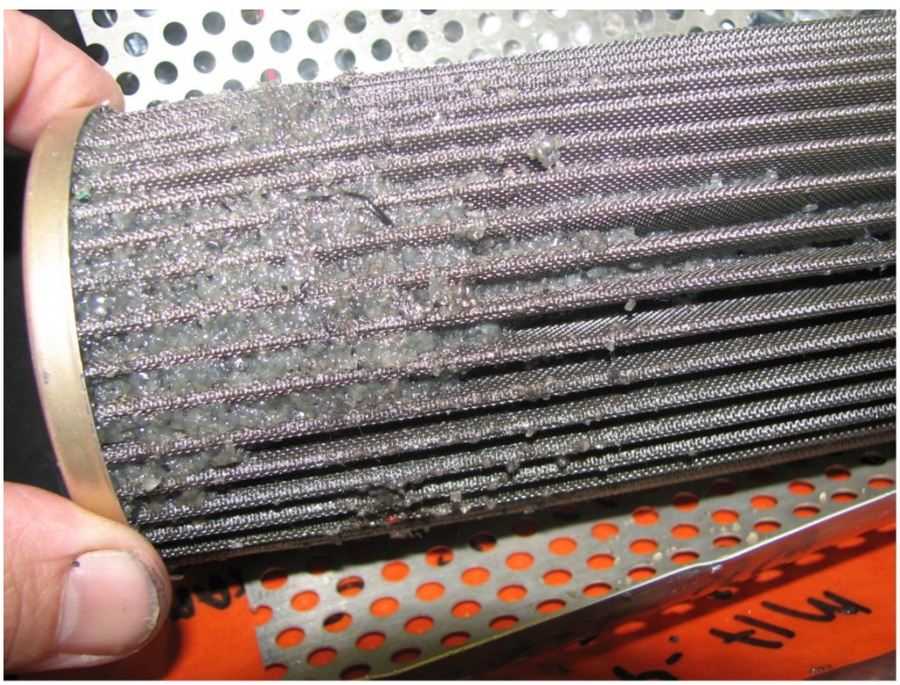

Figure 22. #1 Main Filter (Photo Provided by Goodrich)

Figure 23. Filtered "Smudge" (Photo Provided by Goodrich)

2.5 Field Issue #1 Conclusions

Several fuel filters from aircraft MH-47E, A/C 92-00403 were analyzed to determine the contamination products plugging the filters. The analyses included copper sulfate analysis, elemental analysis by EDS, FTIR, and optical documentation. With the exception of the copper sulfate test, all data indicates the contamination is not only SAP media migration but also that water absorbent element or elements ruptured during operations either at Fort Campbell or overseas. Goodrich found additional debris that was not SAP. Therefore, it appears two failure mechanisms affected the filtration performance of this helicopter.

3.0 FIELD ISSUE #2

3.1 Objective

The objective of the analysis for Field Issue #2 was to identify the debris provided by the U.S. Army Aviation Engineering Directorate from 469.

3.2 Methodology

A fuel sample and debris from the left hand tank from 469 were sent to SwRI for analysis (Figures 24 and 25, respectively). The fuel arrived in a plastic bottle but was transferred to a glass container to illustrate the floating debris in the fuel. Two 100-mL samples were filtered through 0.8-μm membranes, and the gravimetric results are shown in Table 2. The fuel sample contained a large quantity of dark particles that appeared to be elastomeric or rubber. There were also large white particles floating in the fuel. All the debris would eventually settle to the bottom of the container. Upon completion of the gravimetric and elemental analysis, the membrane was treated with copper sulfate to determine if SAP was present.

The debris from the left hand fuel tank was dried when received. When water was applied to the debris, it had the consistency of SAP.

Figure 24. Fuel Sample From 469

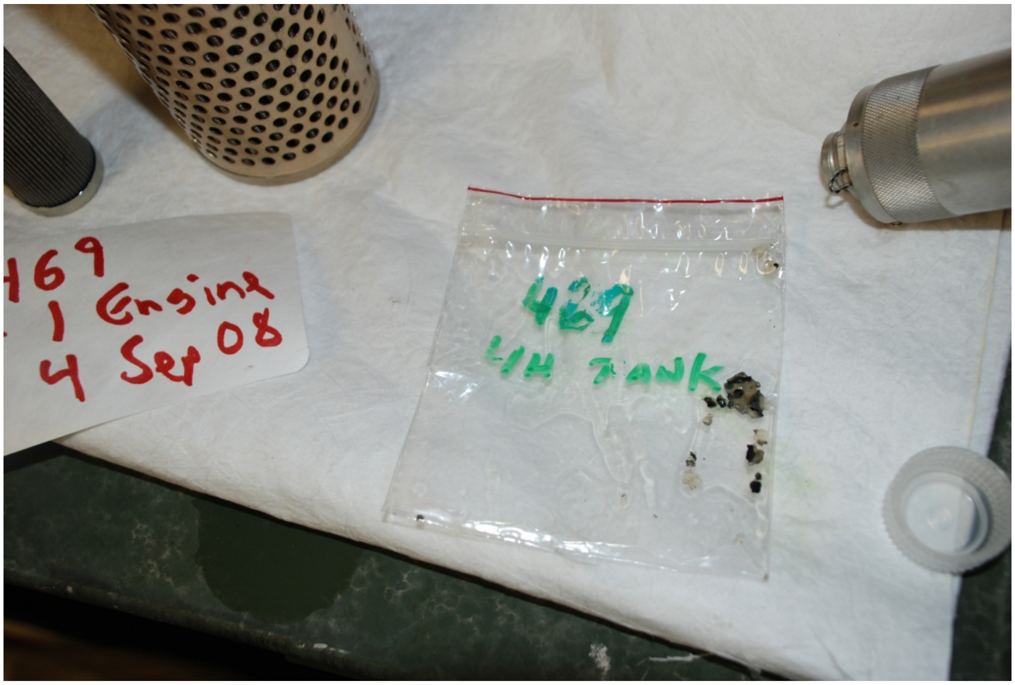

Figure 25. Debris From L/H Tank – 469

Table 2. Gravimetric Analysis of Fuel Sample From 469

Fuel Sample	Gravimetric Analysis, mg/100mL
Sample 1	1.3
Sample 2	1.7

Optical analysis of the debris revealed the size of the darker debris to be 1,000-µm or larger (Figures 26–27). Figures 28–29 illustrate the other debris from the supplied fuel sample. Small blue particles can be seen in Figures 28–29. These particles reacted with the copper sulfate solution that was applied to the membrane to determine if super absorbent polymer (SAP) was present. A few positives were found indicating some SAP migration occurred. It is difficult determine exactly what the white debris was, but it did look gelatinous and would plug a fuel filter rapidly.

Elemental analysis of the captured debris is shown in Table 3. The bulk of the analysis revealed metals that are most likely found in the fuel system along with silica and calcium that is most likely dirt/sand.

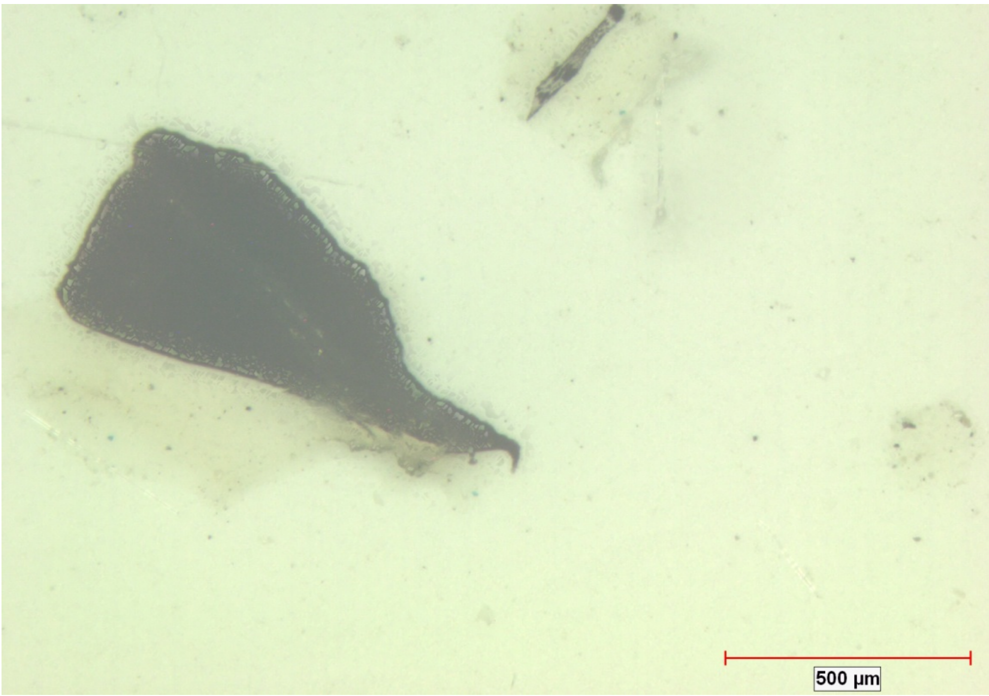

Figure 26. Fuel Sample Debris, 50X

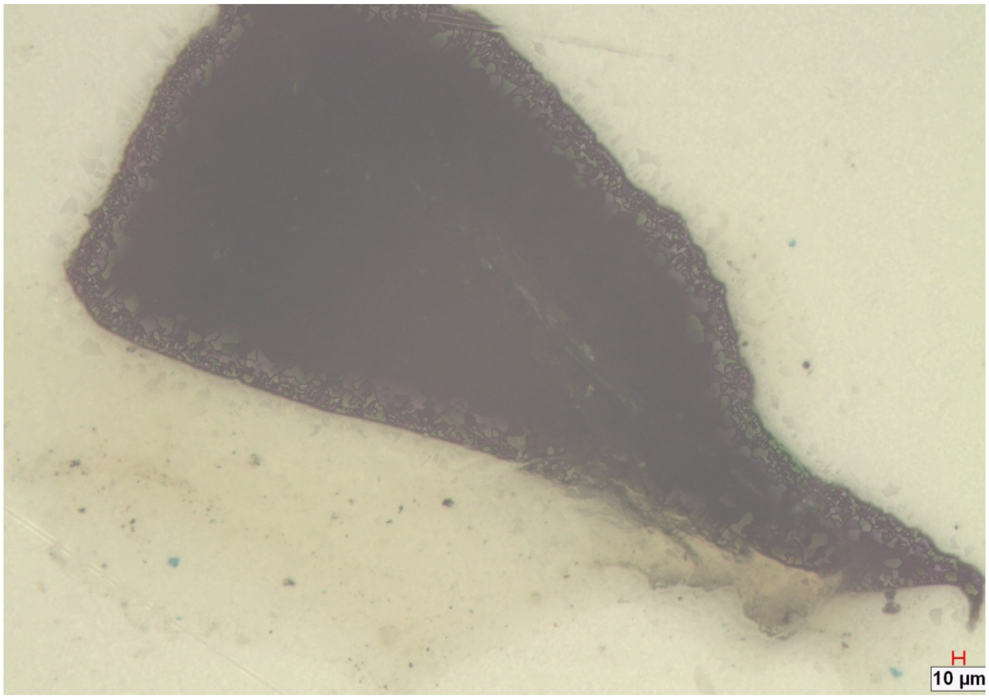

Figure 27. Fuel Sample Debris, 100X

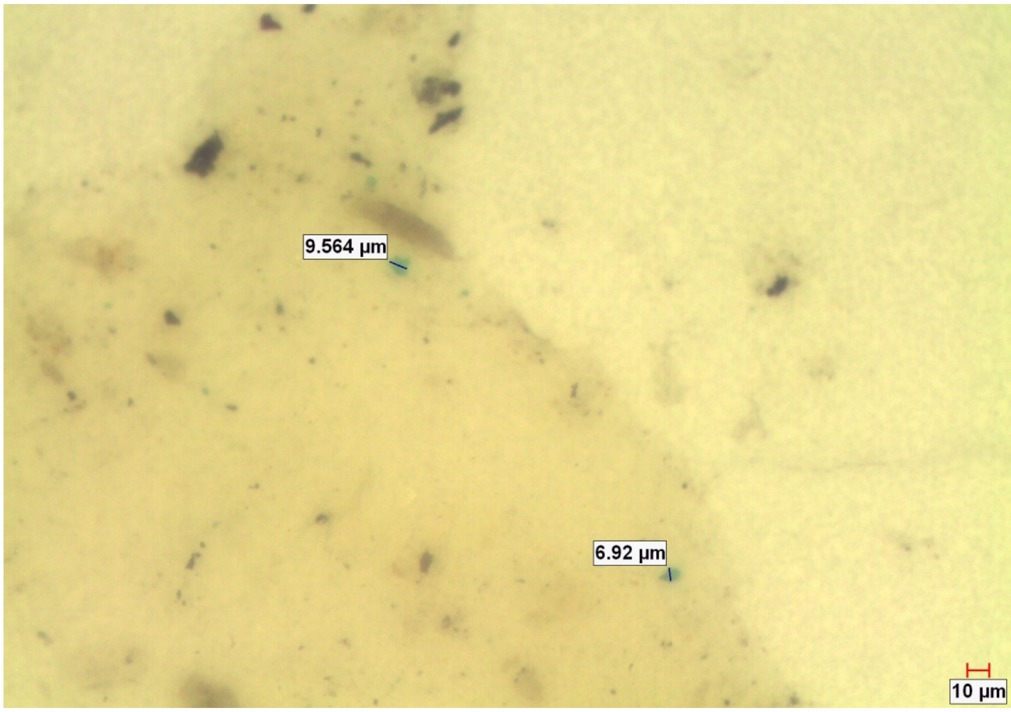

Figure 28. White Debris From Fuel Sample, 100X

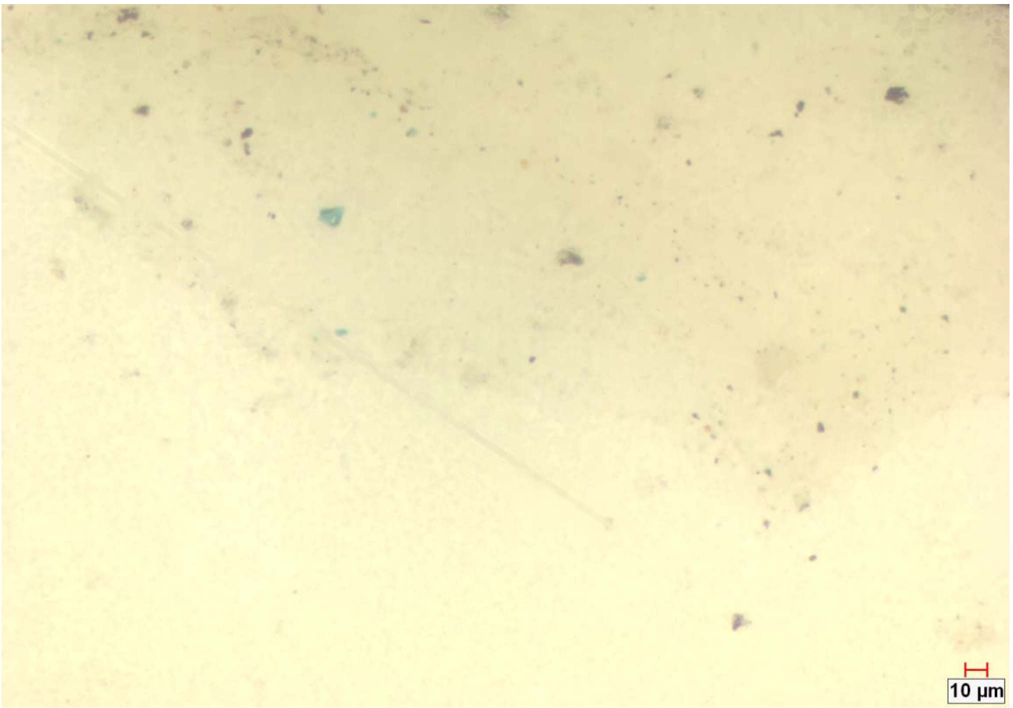

Figure 29. White Debris From Fuel Sample, 200X

Table 3. Elemental Analysis of Fuel Debris

Element	Weight Percent
Mg	25.55
Al	17.89
Si	9.60
S	13.42
Fe	30.26
Ni	2.04
Ca	1.24
Note: Results do not include elements with Z<11 (Na)	

3.3 Field Issue #2 Conclusion

This fuel sample was heavily contaminated with black and white large particles. The black particles appear to be part of the fuel tank or particles from a refueling hose. The white debris shows indications there is SAP present. If the rest of the gelatinous material is not SAP, at this time it is not known what it is. The material, however, would definitely plug fuel filters. One possible explanation for the gelatinous debris not turning blue when treated with copper sulfate is that the magnesium and/or aluminum have already reacted with the metal in the SAP. Therefore, the copper would not react, and the polymer would not turn blue.

4.0 FIELD ISSUE #3

4.1 Objective

The objective of Field Issue #3 was to identify the contamination debris found in an internal helicopter fuel bladder.

4.2 Methodology

A fuel sample and part of an internal helicopter fuel bladder were provided to SwRI to determine if the "black" debris in the fuel was the bladder or other contamination. Figures 30 –35 illustrate the bladder and the problems encountered in the field.

Figure 30. Helicopter Fuel Bladder

Figure 31. Unknown Contaminant in Fuel Bladder

Figure 32. Close up of Fuel Contaminant in Fuel Bladder

Figure 33. External View of Fuel Bladder

Figure 34. External View of the Degraded Fuel Bladder – View 1

Figure 35. External View of the Degraded Fuel Bladder – View 2

Approximately 100 mL of fuel was provided from the fuel bladder. The furnished fuel was filtered through laboratory membranes to capture the dark particles, Figure 36. The debris plugged the laboratory filters very quickly. Multiple membranes were required to filter all of the debris, Figure 37.

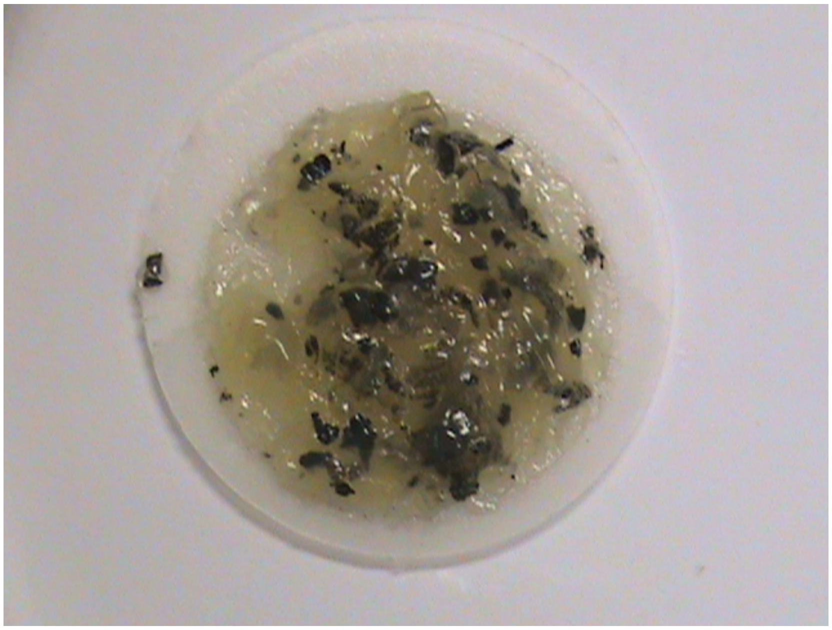

Figure 36. Fuel Debris Captured on Laboratory Membrane

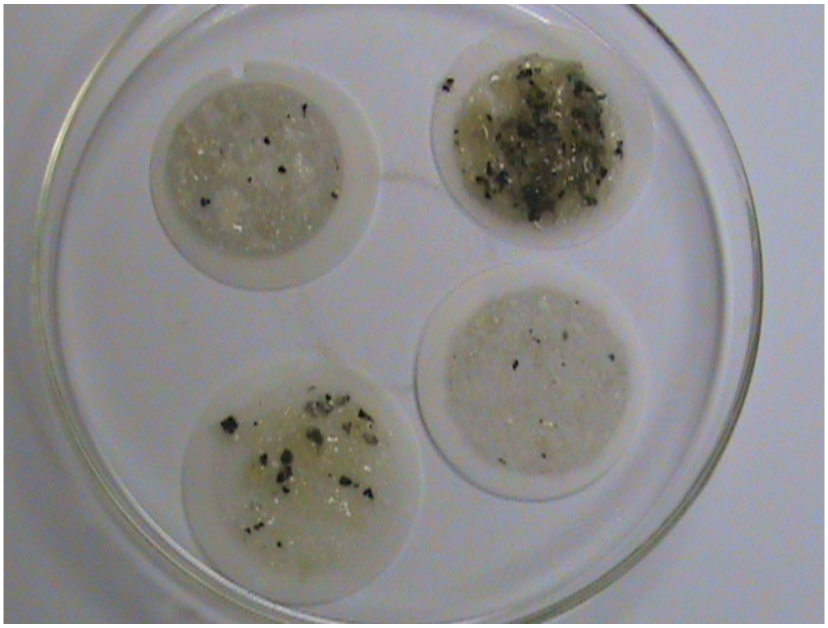

Figure 37. Multiple Laboratory Membranes Containing Fuel Debris

Elemental analysis of the bladder and jelly-like material was performed by EDS, Table 4. The jelly-like debris did contain the dark particles shown in Figures 36 and 37. The jelly-like debris is tacky and if left in the air, it will dry out.

Table 4. Elemental Analysis of Bladder and Jelly-Like Debris

Element	Black Particles	Jelly-Like Debris
Na	8.67	3.27
Mg	22.76	49.68
Al	0.83	6.79
Si	29.22	1.76
S	14.24	33.32
Cl	3.07	3.93
K	0.63	1.25
Ca	2.72	---
Fe	0.77	---
Zn	17.09	---

Note: Results do not include elements with Z<11 (Na)

FTIR analysis was performed on the jelly-like material with the spectrum shown in Figure 38.

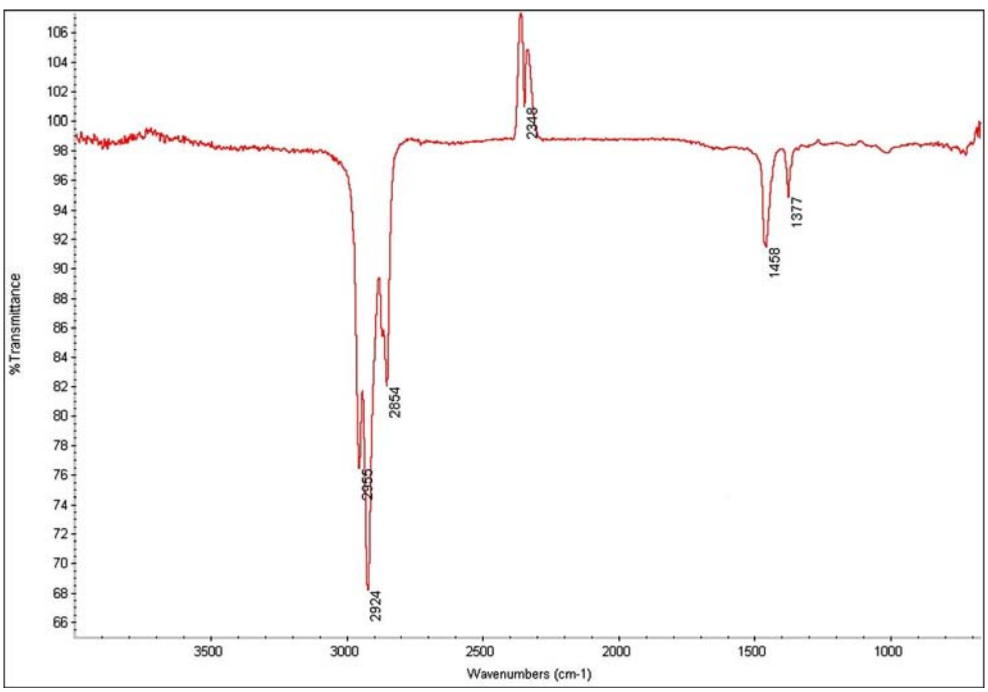

Figure 38. FTIR of Jelly-Like Debris

The FTIR scan only shows carbon and hydrogen peaks.

4.3 Field Issue #3 Conclusions

The debris has the appearance and consistency of apple jelly which is typically cause by the combination of water, fuel system icing inhibitor, and super absorbent polymer (SAP) from water absorbent monitors. However, none of the analysis supports this conclusion. It appears that this contaminant very well may have been dispensed into the bladder (Figures 31 and 32).

The elemental analysis suggests salt (NaCl) maybe present, and the sulfur is most likely from the fuel. The high levels of magnesium are not typical and the source is not known without further investigation. With the analysis that was completed on this debris, it is not known what it is or its source.

The dark particles do not appear to have come from the fuel bladder, but from another source such as o-rings or sealants.

It is recommended that further analysis of the internal surface of the bladder and support structure be performed to determine failure mechanism and/or identify any corrosion activity.